Document number

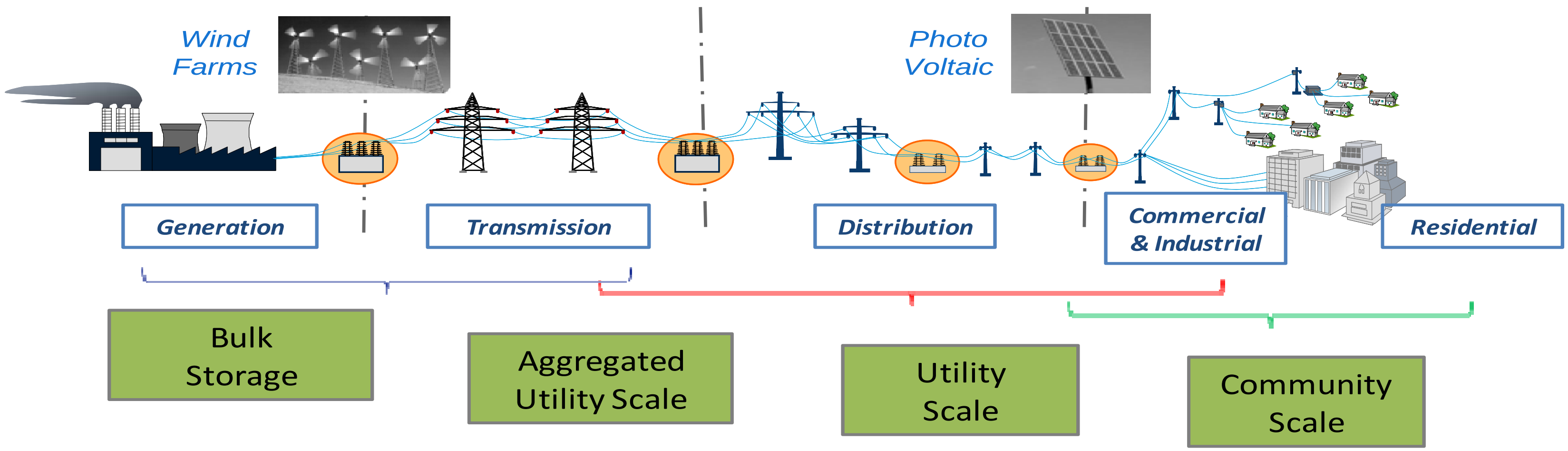
DNV KEMA Storage Models Summary
CPUC Workshop

December 3, 2012

Today's Discussion

- Key Points Regarding Analysis
- Listing and Description of DNV KEMA Tools
- Mapping of Tools to CPUC Projected Use Cases
- Model Demonstrations

Distinct Models are Utilized for Each Domain



Wholesale/Bulk

Peaker Model
DNV KEMA KERMIT
Plexos

T & D Systems

Storage Distribution Valuation tool

End Use

DNV KEMA Microgrid Optimization Tool

Drivers for Evaluation Approach and Storage Models

- Assessments need to be conducted at the fidelity necessary to ensure storage is accurately assessed from all perspectives
  - Accuracy and fidelity of the tools utilized is essential for acceptance of results by the broad, diverse stakeholder groups participating in the cost effectiveness process
- All benefits of storage need to be taken into account
  - Limiting the benefits streams or not accounting for the multiple-application potential of storage technologies may lead to false conclusions
- Benefits Assessments must be Realistic
  - Real world constraints, non-linearities, and points of diminishing returns must be recognized and factored into calculations

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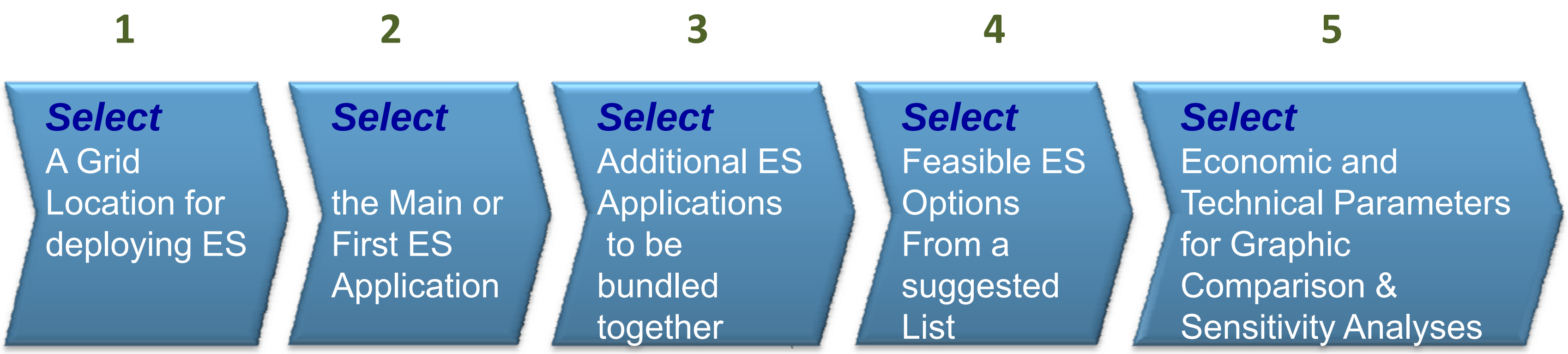
DNV KEMA Suite of Evaluation Tools for Energy Storage

Applications	Drivers	DNV KEMA Model
All applications	Composite of all drivers below…	ES-Select
Distributed Energy Storage / Community Energy Storage	EV / PV penetration, reliability, asset optimization	Storage Distribution Circuit Model
Bulk Storage, Spinning Reserve, Load Following, Regulation	Wind penetration, policy	KERMIT PLEXOS
Peak power substitution	Flexibility, siting and emissions Issues	Peak Power Substitution Model
End Use, Demand-side management, time shifting	Microgrids, behind the meter DG and Storage, Demand Response, EE, Reliability	MicroGrid Model
T&D deferral / upgrade / substitution	Cost, policy, environmental factors, uncertainty	T&D Capital Deferral Model

ES-Select Overview

In a step-by-step interactive manner, ES-Select identifies and compares the feasible Energy Storage (ES) options for different grid applications

1. Asks: Location
2. Asks: Main Application
3. Option for: Additional Applications
4. Offers: Feasible ES Options
5. Compares the feasible ES Options



Total Value of Bundled Applications

The total value of bundled applications is the sum of the "utilized" or realizable values of each application

Total Value =	100% x Value 1	First (top Priority) application
	+ $\mathbf{UF_2}$ x Value 2	second application
	+ $\mathbf{UF_3}$ x Value 3	third application
	+ $\mathbf{UF_4}$ x Value 4	fourth application
	+ …	

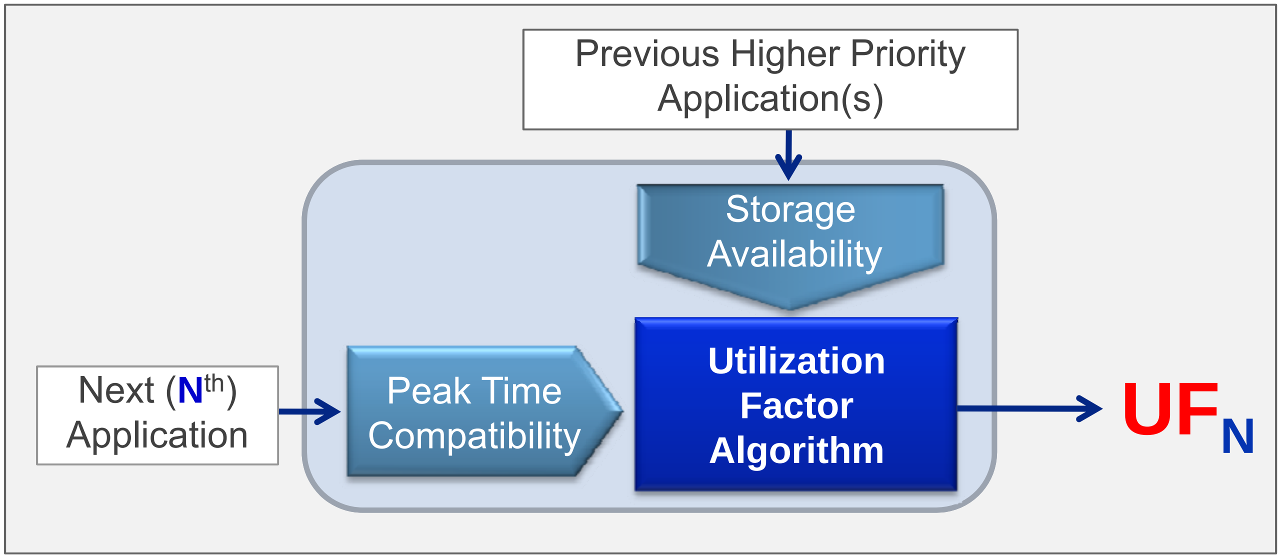
UF = Utilization Factor = portion of each application value that can be realized in the bundle of applications

Calculating Utilization Factors

DNV KEMA developed a process to quantify utilization factors (UF) for bundled applications.

Combined Benefit = Bundle Benefit + UF x Benefit of Next Application

$$UF = \frac{\text{Value of a storage application in a bundle}}{\text{Value of the application by itself (no sharing of storage capacity)}}$$



Substantiated Utilization Factors (UF)

Following are four Bundling cases for which utilization factors have been calculated using real data from utility (loading), PJM (regulation) and NREL (PV output)

	Range
T&D deferral (V1) + Area Regulation (V2) =	$V1 + \underbrace{(85\% - 98\%)}_{\text{Range}} V2$
Retail Time of Use + Area Regulation =	V1+ (70% - 72%) V2
Solar Firming + Area Regulation =	V1+ (50% - 60%) V2
Solar Energy Time Shift + Area Regulation =	V1+ (35% - 55%) V2

Storage Distribution Valuation Model Overview

User Interface
Input profile assumptions

Distribution Circuit Model(s)
Circuit assumptions (OpenDSS)

Model Data Processing
Storage project assumptions

Select

Inputs

Load profiles
EV / no EV
PV / no PV (customer vs. util)
Storage / no storage
Storage control priority
Reliability event

Run

Engineering Outputs

kW delta (time)
Energy kW
Voltage Levels (time)
Harmonics
Equipment Usage (#)
Storage Usage (# cycles)

Analyze

Translation

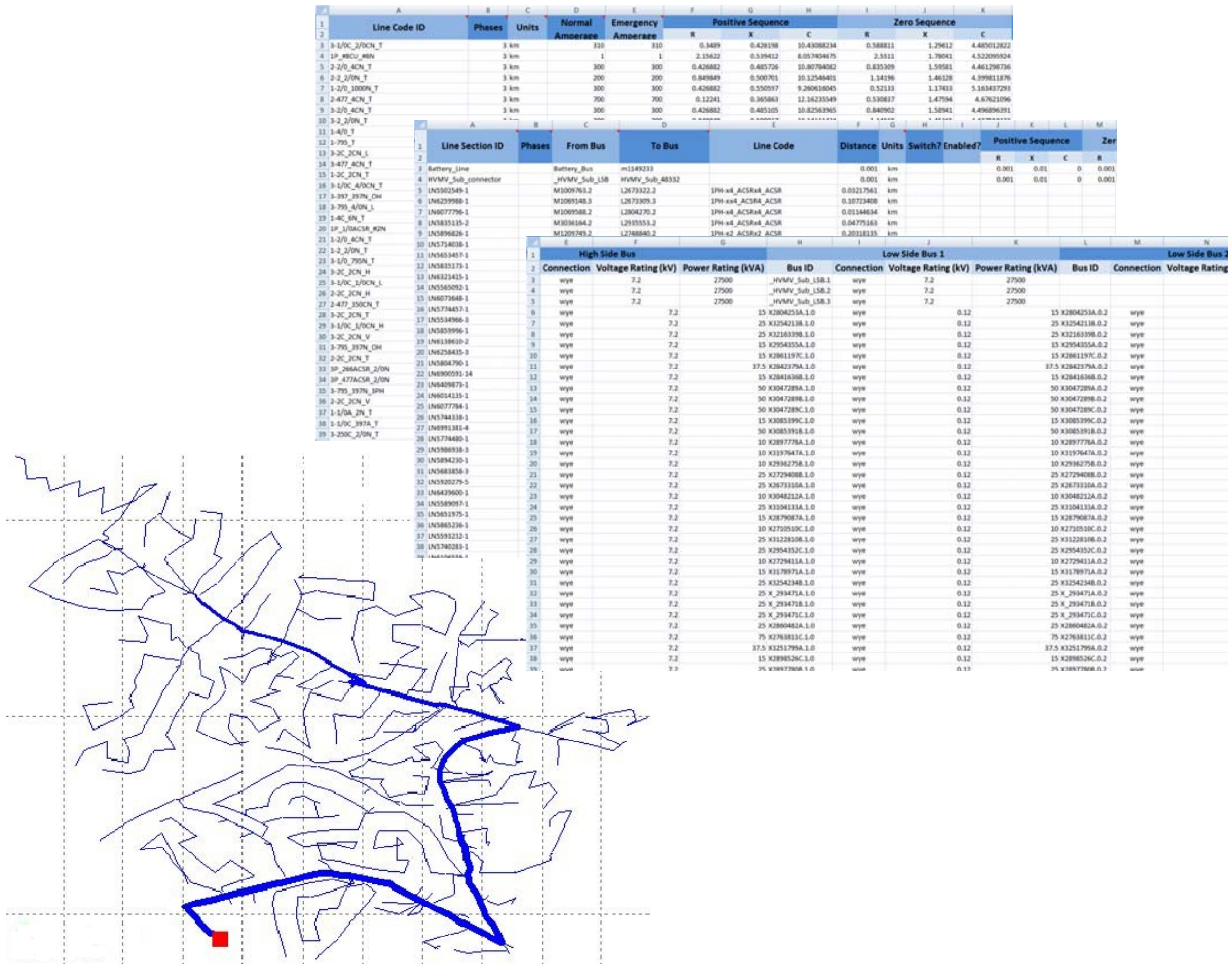
Capacity
Energy shifted
Energy savings
Power Quality Δ
Reliability Δ
Asset lifetime
Storage lifetime

Financial Outputs

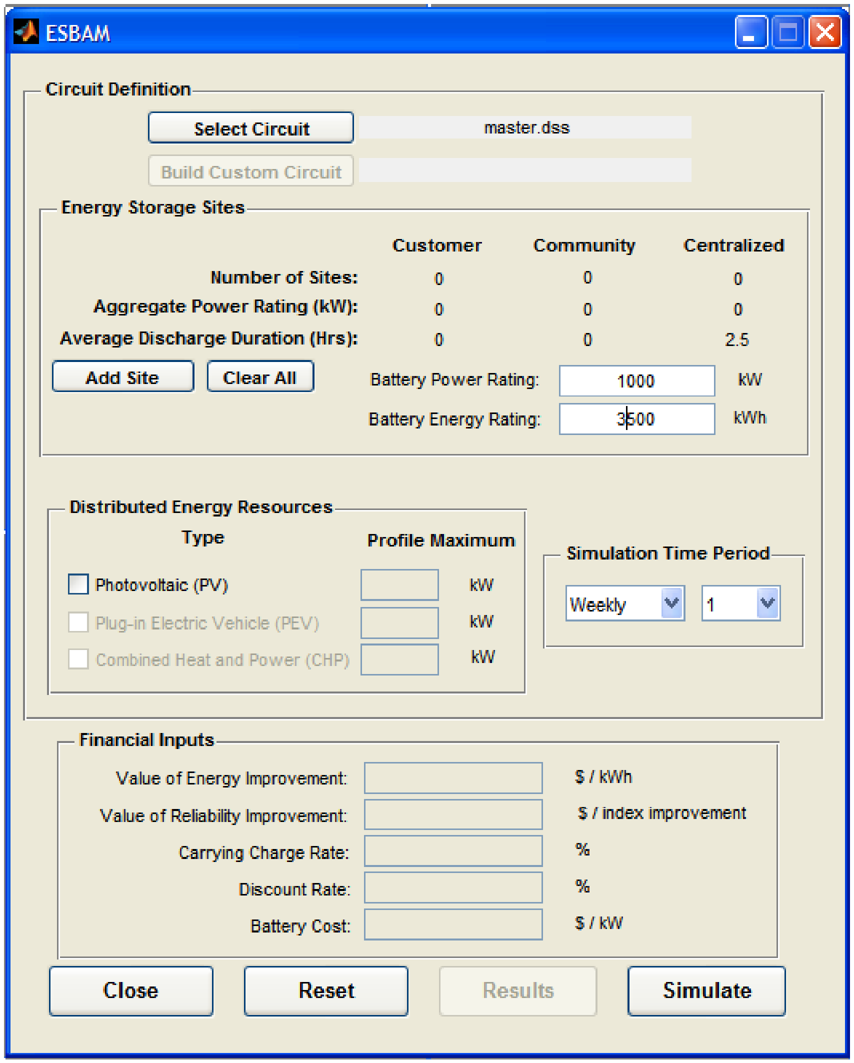
Storage costs
Storage benefits
  Avoided costs
  Earnings
Alternative benefits
Asset loss of life
Deferral values

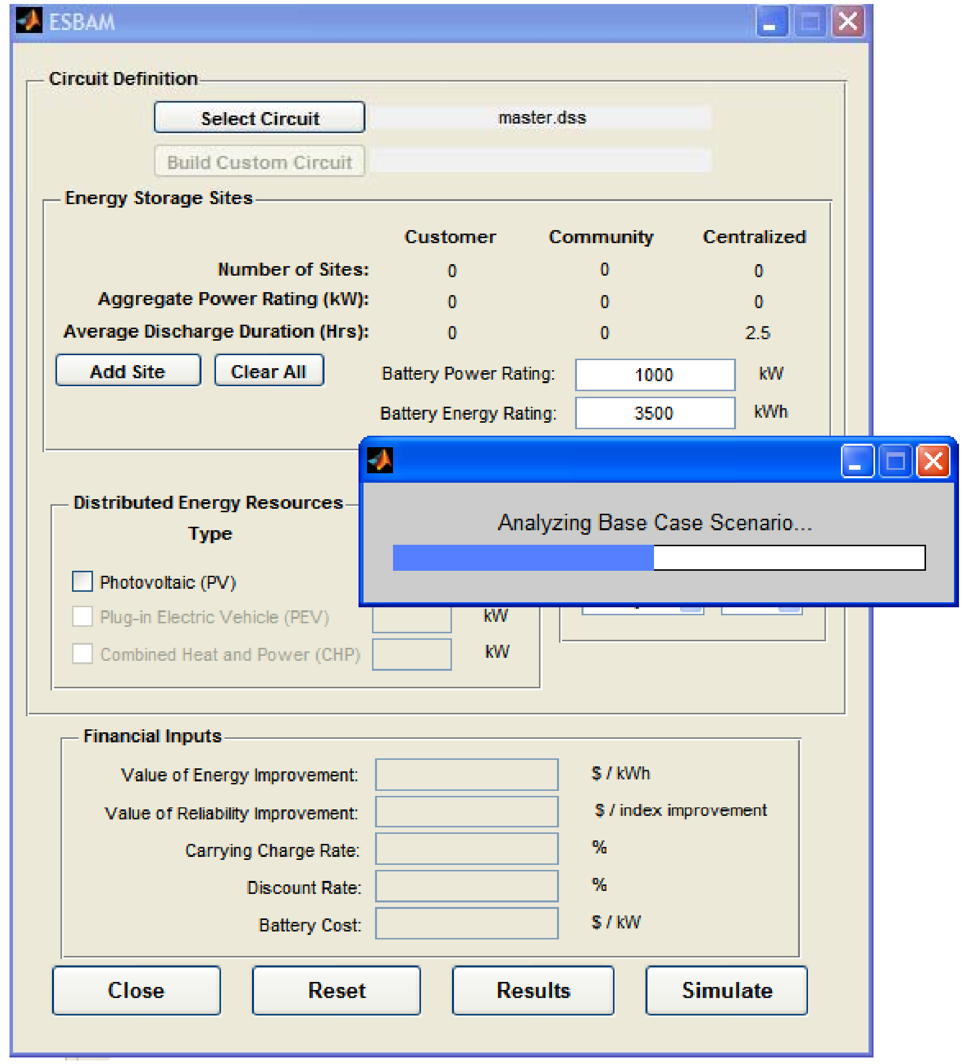
Circuit Data Easily Uploaded for Customized Study

- Substation
  - Capacities
  - Settings
- Line sections
  - Wire impedance
  - Nodes
- Regulators, Capacitors
- Loads
  - Load profiles
  - EV load profiles
- Distributed Generation
  - Photovoltaic (PV)
  - Generation profiles
- Reliability Data
- Demand Response Data



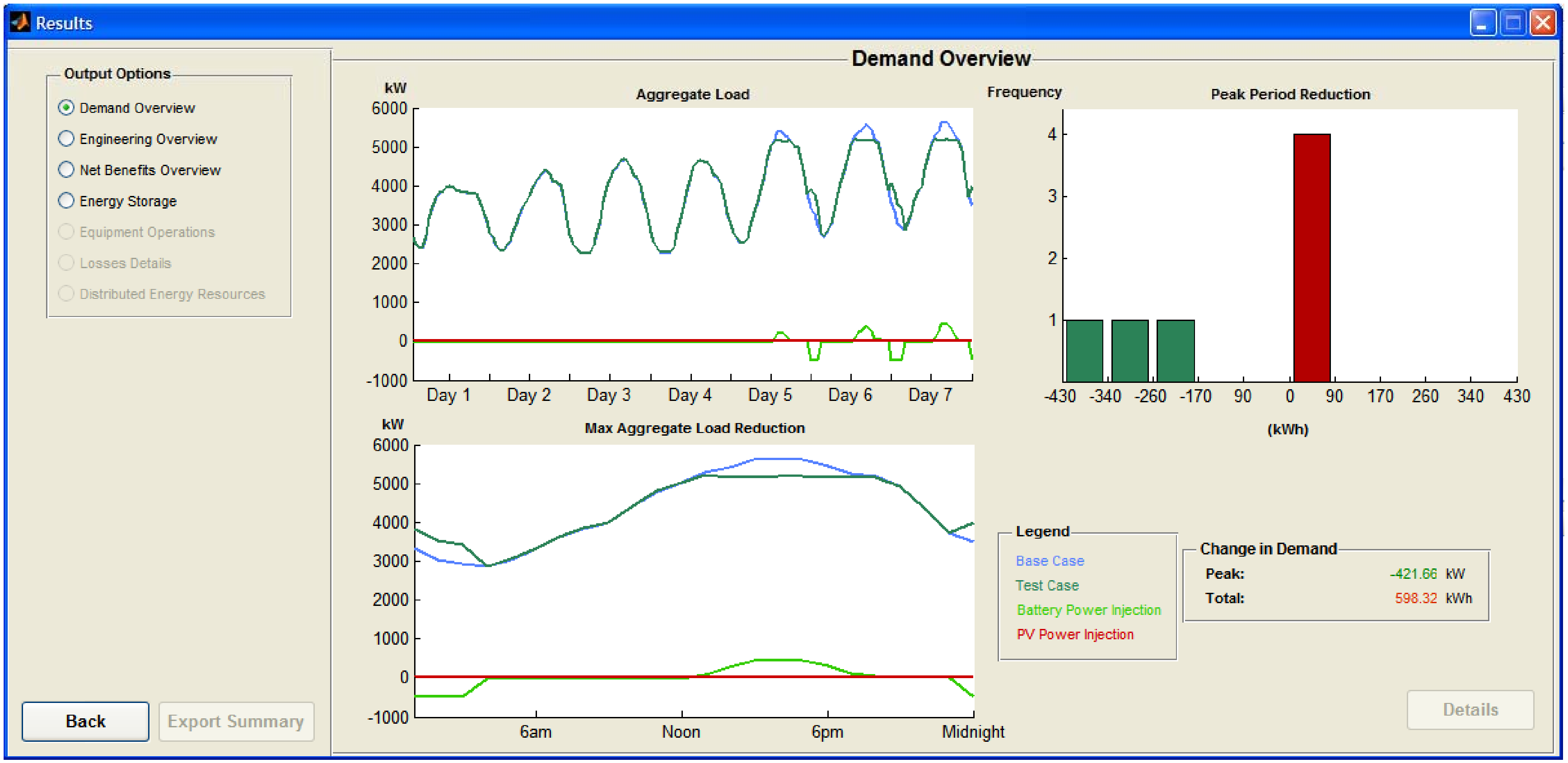
Input Screen for Model





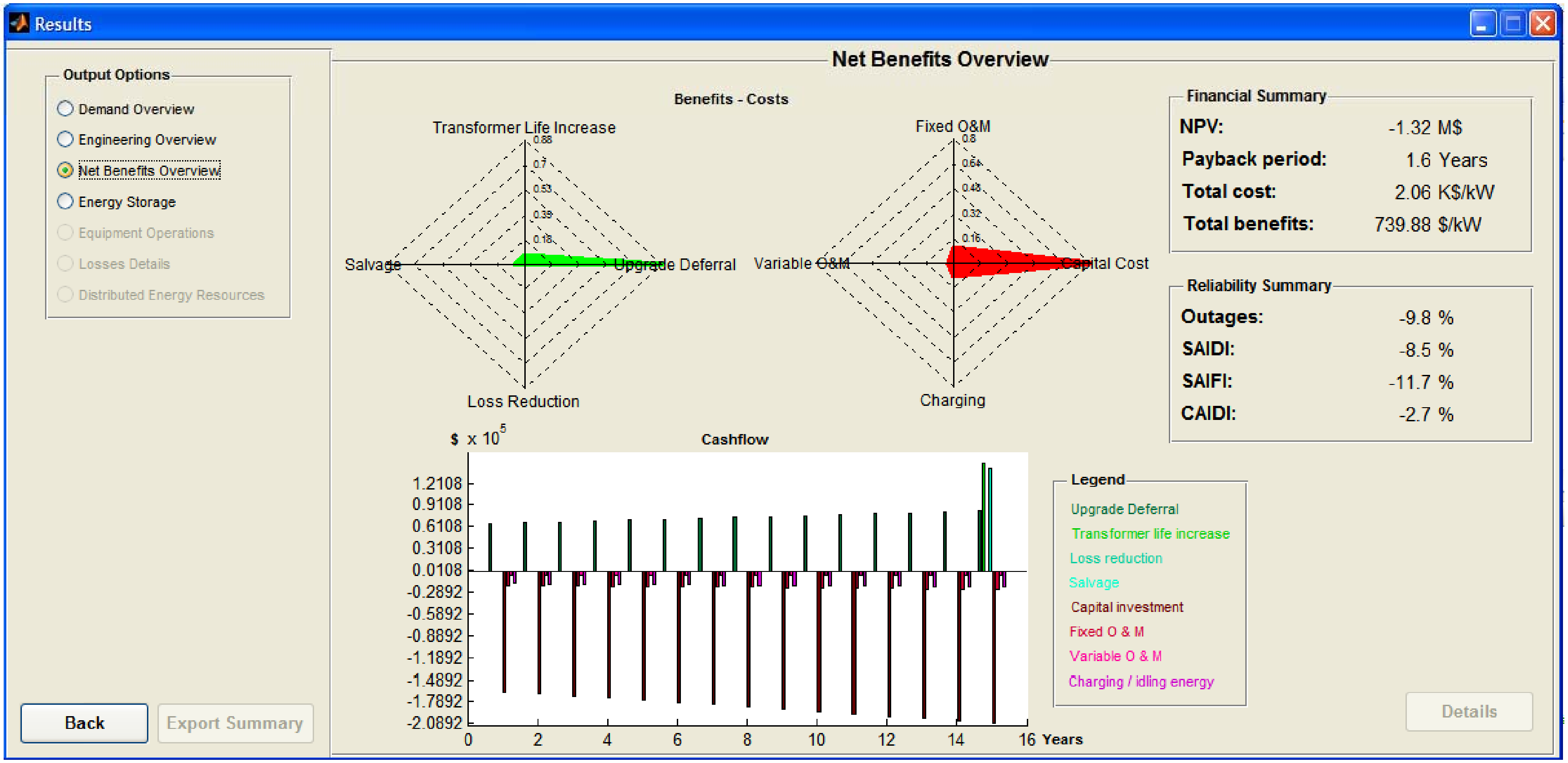
Source: DNV KEMA

Sample Results of Model: Benefits



Source: DNV KEMA

Sample Results of Model: Financial Factors

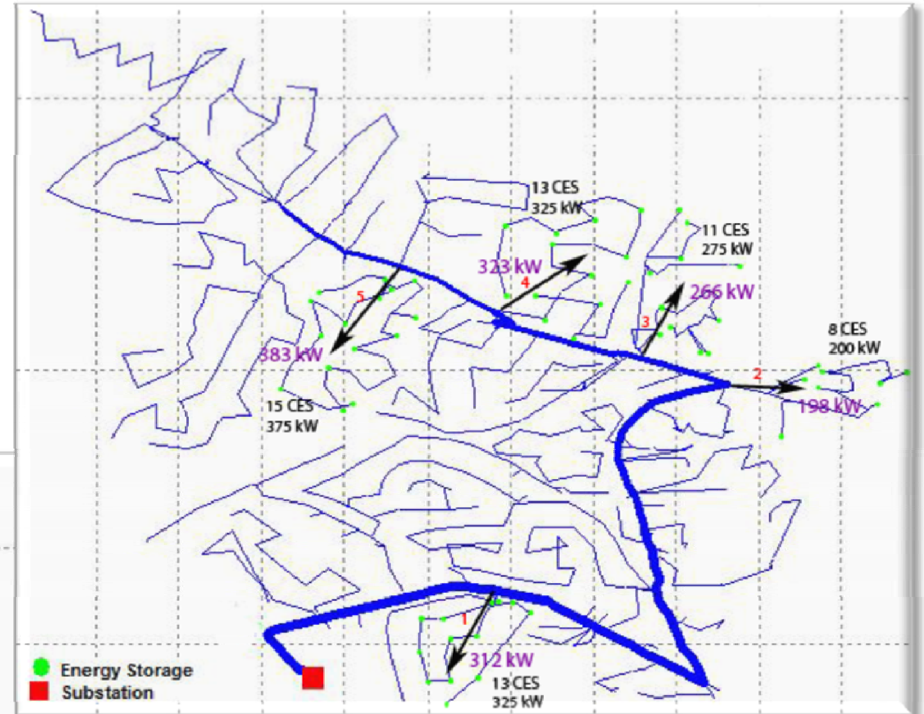


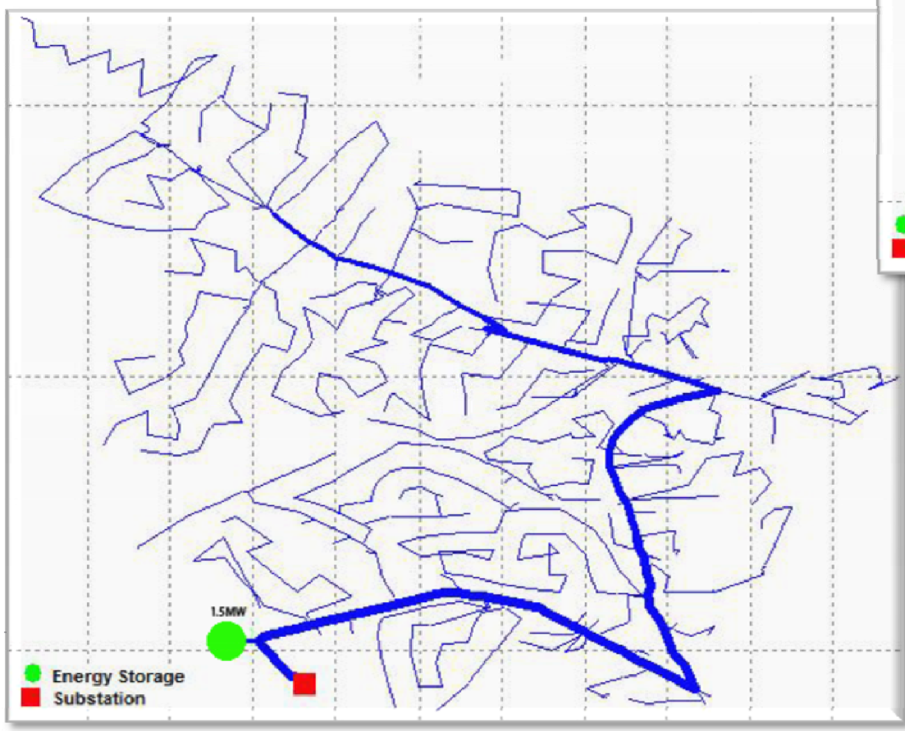
Source: DNV KEMA

Distributed Storage: Multiple versus a Single Unit

<u>Substation versus edge of Grid</u>

- Difference in performance
- Difference in benefits
- Difference in costs





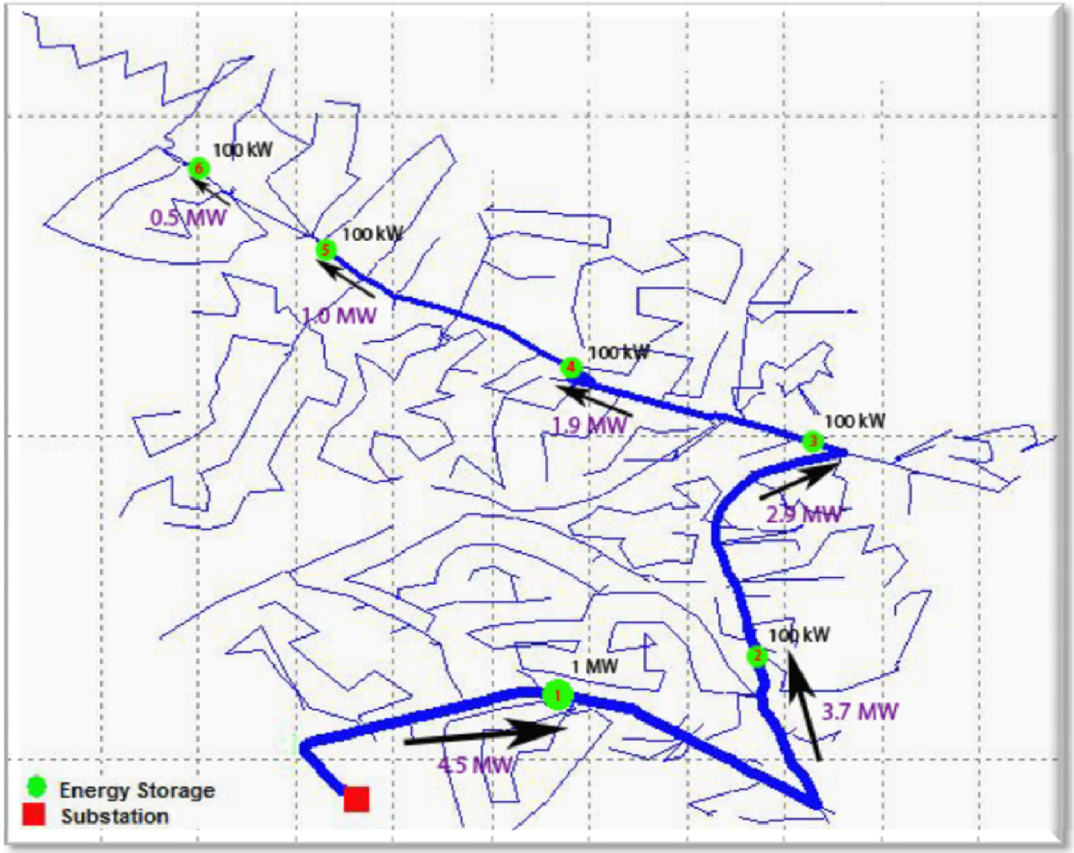
Site	Peak Demand (kW)	Peak Demand (kVA)	# of Devices	Capacity (kW)
1	312	386	13	325
2	198	244	8	200
3	266	320	11	275
4	323	399	13	325
5	383	474	15	375

Assessing Storage Locations

Meeting Circuit Needs

- Storage solution tailored to circuit
- Evaluates multiple options
- Allows for identification of best value options

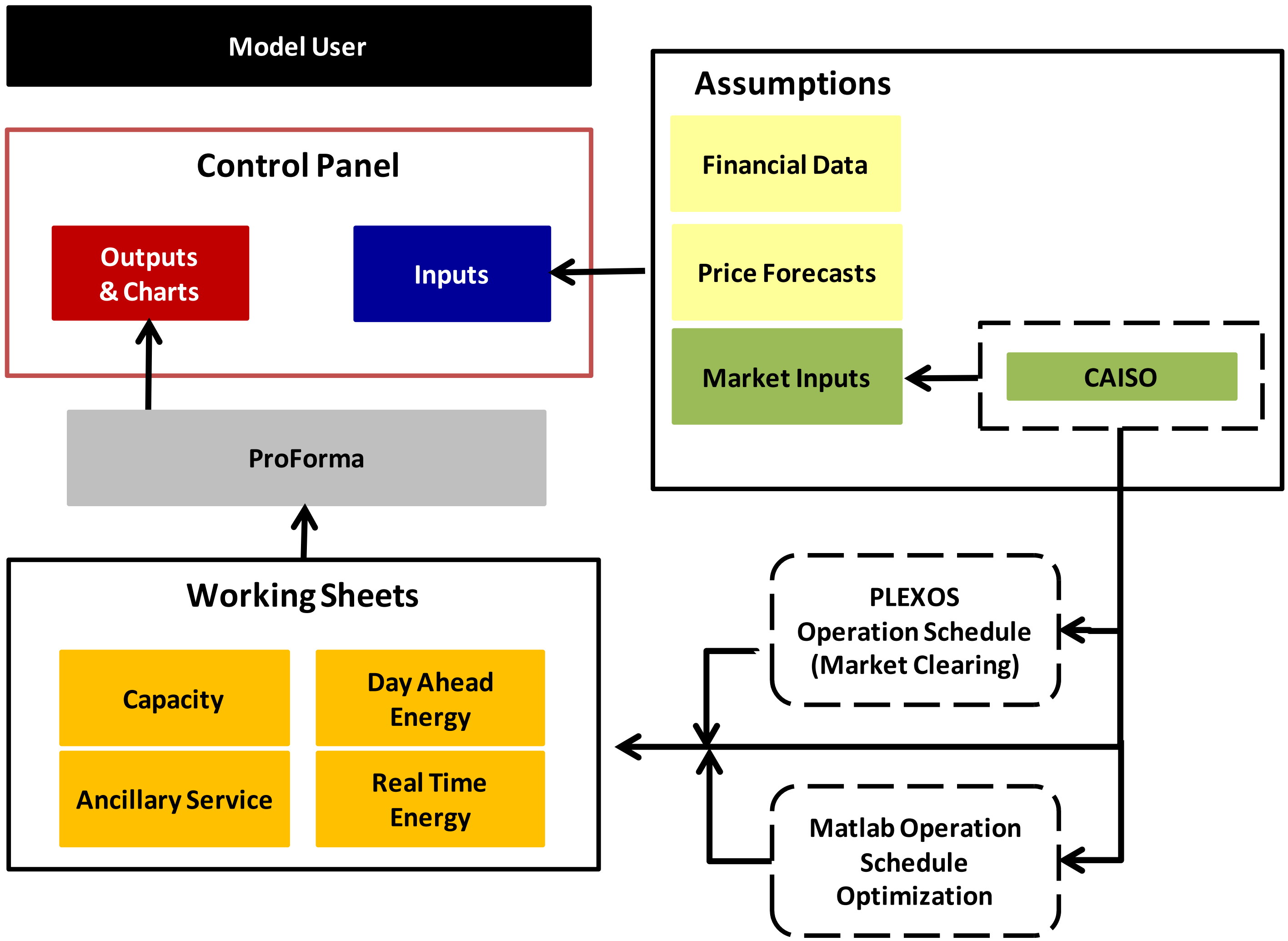
Example shows different storage sizes as a possible solution



Site	Peak Demand (kW)	Peak Demand (kVA)
1	4,555	5,079
2	3,716	3,716
3	2,876	3,031
4	1,853	1,868
5	992	1,231
6	453	576

Peaker Model Overview

- The model explores storage use for both energy and ancillary services
- Schedules are developed based on co-optimized performance in energy and ancillary markets
- Performance schedules can based on historical market prices (Matlab) or in simulated market clearing (PLEXOS)
- Schedules feed into financial calculations



Financial Input Assumptions

- Operating schedules feed into financial calculations
- The financial calculations capture net value over equipment lifetimes
- This approach captures the dynamics of operating costs, tabulating costs and benefits based on performance

Control Panel Inputs

Step 1: Choice of Market

Please choose the market	CAISO	
Energy Market	Base	Override
DA Market	Yes	
RT Market	Yes	
Capacity Market	No	
A/S Market	Yes	

Step 2a: Storage Cost & Performance Assumptions

	Base	Override
System Size (MW)	10.00	
Storage (hours)	3.00	3.00
CAPITAL COSTS		
Power CAPEX ($/kW)	$1,000	
Energy CAPEX ($/kWh)	$100	
Balance of Plant ($/kW)	$200	
SYSTEM COST ($/kW)	$1,500	
PERFORMANCE		
Roundtrip Efficiency	63%	
Lifetime (years)	20	
O&M		
Fixed ($/kW-yr)	$13.00	
Variable ($/kWh)	$0.004	

Step 2b: Peaker Performance Parameters

	Base	Override
Peaker Capacity (MW)	10.3	10.3
Min Stable Level (MW)	4.5	4.5
Load Point 1 (MW)	4.5	4.5
Load Point 2 (MW)	6.7	6.7
Load Point 3 (MW)	8.6	8.6
Heat Rate 1 (Btu/KWhr)	13550.0	13,550.0
Heat Rate 2 (Btu/KWhr)	10200.0	10,200.0
Heat Rate 3 (Btu/KWhr)	9800.0	9,800.0
VO&M Cost ($/MWhr)	5.0	5.0
Start Cost ($)	5280.0	5,280.0
Min Up Time (hrs)	2.0	2.0

Step 2c: Peaker Cost

	Base	Override
CAPITAL COSTS		
CAPEX ($/kW)	$1,394	
PERFORMANCE		
Lifetime (years)	20	
O&M		
Fixed ($/kW-yr)	$24.00	
Cost of gas ($/MMBtu)	$6.050	

Step 3: Financing Assumptions

	Base	Override
Percent Financed with Equity	40%	
Cost of Equity	16.00%	16.00%
Debt Interest Rate	6.00%	6.00%
WACC	8.53%	
Debt Period in Years	20	

Step 4: Depreciation

	Base	Override
Fed Depreciation	7	
State Depreciation	20	

Step 5: Tax Rates and

	Base	Override
Federal Tax Rate	35.00%	
State Tax Rate	9.00%	
INVESTMENT TAX CREDIT		
ITC Rate	0.00%	
Fed Depreciation Reduction	0.00%	
OTHER TAX		
Ad Valorem Tax Rate	1.1%	
Insurance Rate	0.6%	

Step 6: Inflation & Escalation

	Base	Override
Fixed O&M Escalation	0.50%	
Var O&M Escalation	0.50%	

Step 7: Application Parameters

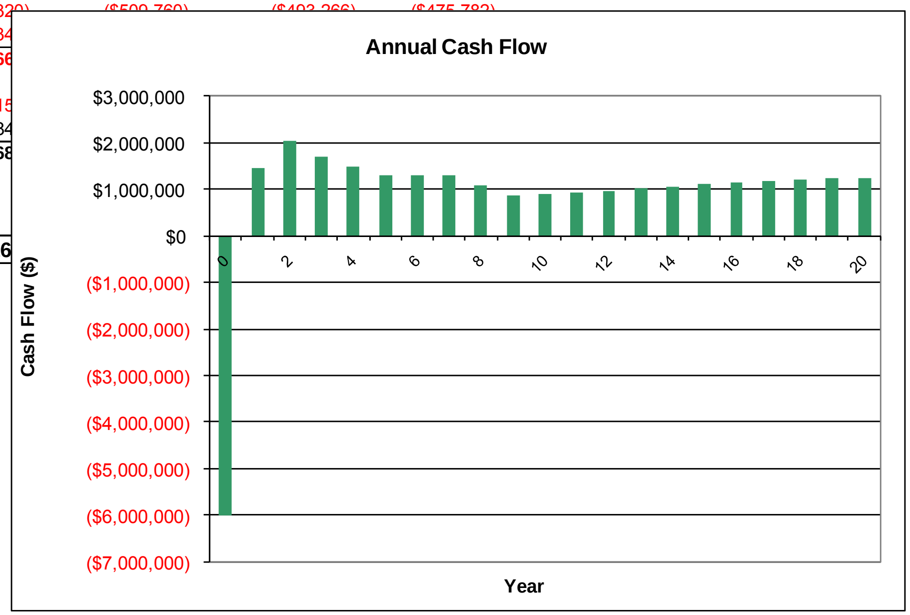
	Base	Override
Capacity Factor	11.3%	

Step 8: Risk Free Interest Rate

	Base	Override
Risk Free Interest Rate	4.0%	

Financial Output

		Fuel/LMP Multiplier	1.011	1.032	1.061	1.077
		2010	2011	2012	2013	2014
Year	**0**	**1**	**2**	**3**	**4**	**5**
REVENUE						
Energy Revenue		***$1,766,365***	$1,786,301	$1,822,187	$1,874,021	$1,901,932
Capacity Revenue		***$755,254***	$763,779	$779,123	$801,286	$813,220
Reserve Revenue		***$0***	$0	$0	$0	$0
Total Revenue (w/ forecast growth)		**$2,521,619**	**$2,550,080**	**$2,601,309**	**$2,675,307**	**$2,715,152**
OPERATING EXPENSES						
Fixed O&M		($130,650)	($131,303)	($131,960)	($132,620)	($133,283)
Variable O&M		($39,688)	($39,886)	($40,085)	($40,286)	($40,487)
Ad Valorem		($165,000)	($156,750)	($148,913)	($141,467)	($134,394)
Insurance		($90,000)	($90,000)	($90,000)	($90,000)	($90,000)
Total Operating Expeses		**($425,338)**	**($417,939)**	**($410,958)**	**($404,372)**	**($398,163)**
Operating Profit		**$2,096,282**	**$2,132,141**	**$2,190,351**	**$2,270,935**	**$2,316,988**
Interest Expense		($540,000)	($525,320)	($509,760)	($493,266)	($475,782)
Loan Repayment Expense (Principal)		($244,661)	($259,34			
Net Finance Costs		**($784,661)**	**($784,66**			
State tax refund/(paid)		($89,440)	($47,15			
Federal tax refund (paid)		$236,831	$739,84			
Taxes Saved/(Paid)		**$147,390**	**$692,68**			
Equity Investment	($6,000,000)					
After-Tax Equity Cash Flow	**($6,000,000)**	**$1,459,011**	**$2,040,16**			



Combustion Turbine versus Storage

Different performance characteristics and costs lead to different operation profiles

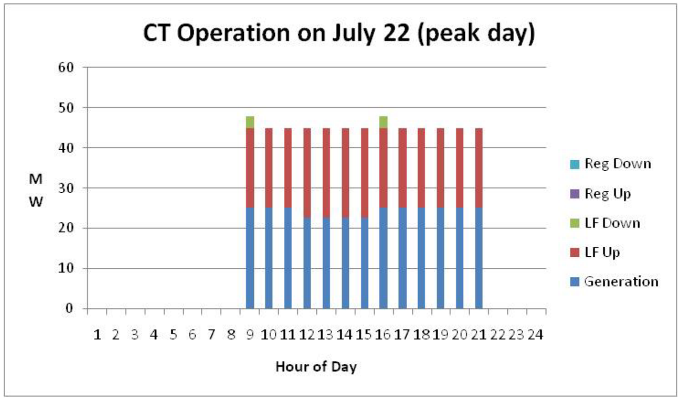
Combustion Turbine

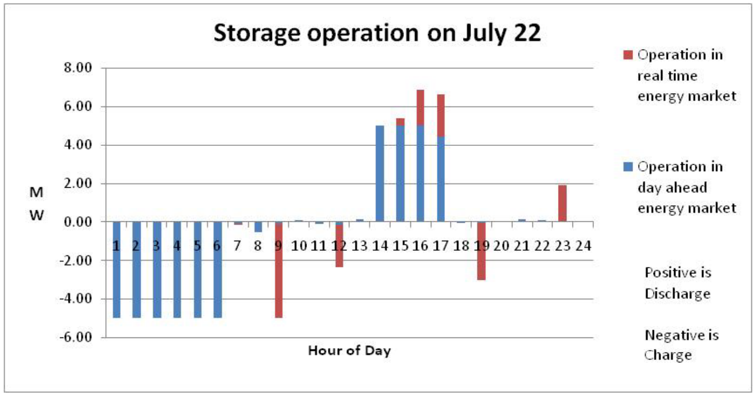
- Constraints: Minimum up/down time, ramp up and ramp down limits
- Cost Factors: Start up shut down costs, variable efficiency based on loading, minimum operating level, fuel input

Storage

- Constraints: Limited duration
- Costs: Charging costs

Sample Unit Operating Profiles



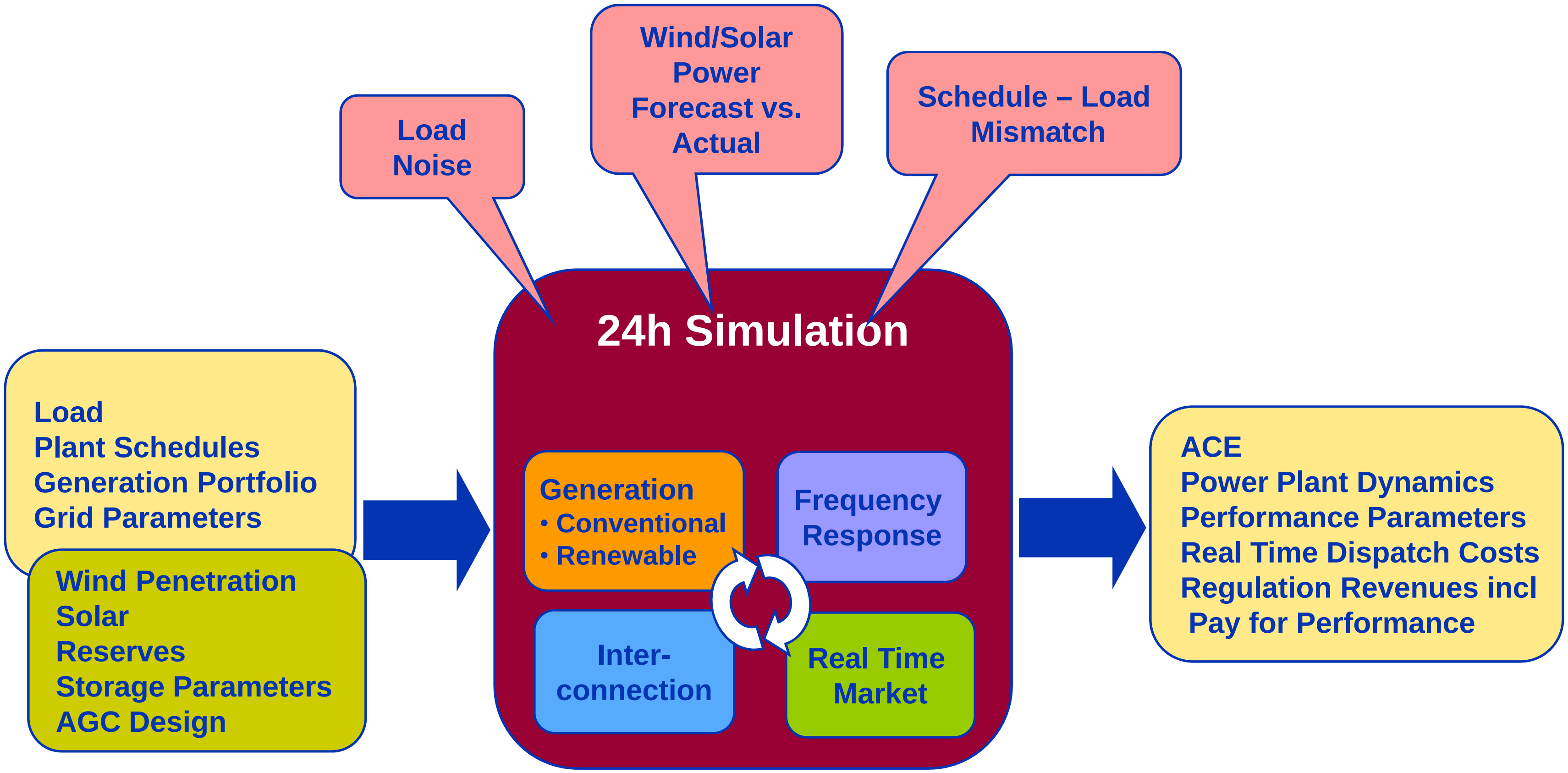


Analysis Value

The analysis evaluates each unit type as it would perform, putting them on a truly comparable basis and capturing real differences in behaviors and economics

- The methodology accounts for differences in operation between a combustion turbine versus energy storage due to different performance and cost characteristics.
- Analysis tools considers participation in multiple market products and captures dynamics of co-optimizing across energy and ancillaries.
- The approach has the potential to explore how storage compares to peaker plants in current and future scenarios, which allows it to capture storage's changing value as the generation fleet evolves.
- The analysis blends DNV KEMA's expertise in market modeling and energy storage, giving an authentic view of market impacts and technology capabilities.

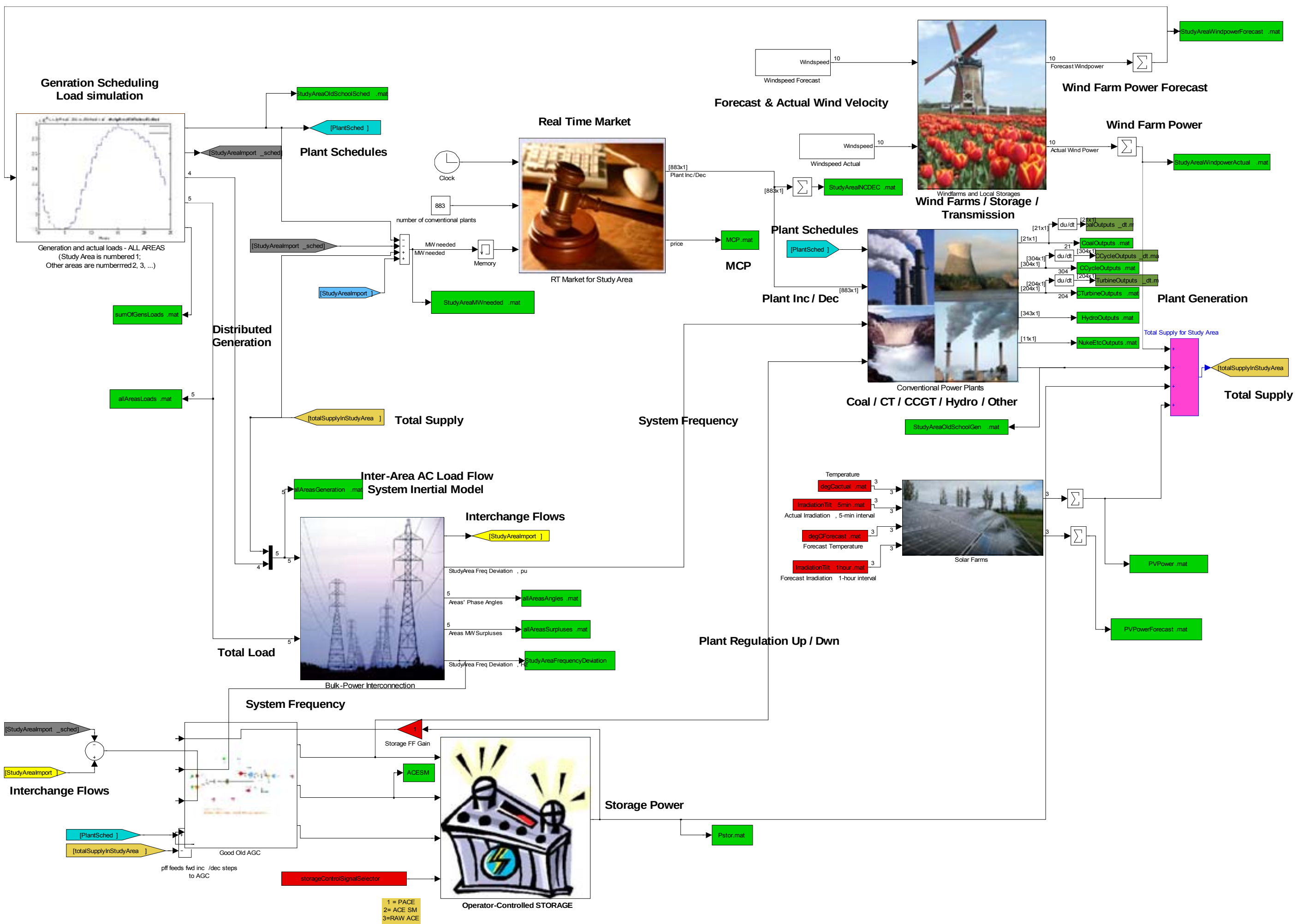
Overview of KERMIT Simulation Tool



KERMIT is the Definitive Tool for AGC and Real Time Assessment and Design – Renewables Integration, Use of Storage and Fast Resources, AGC and Dispatch Design

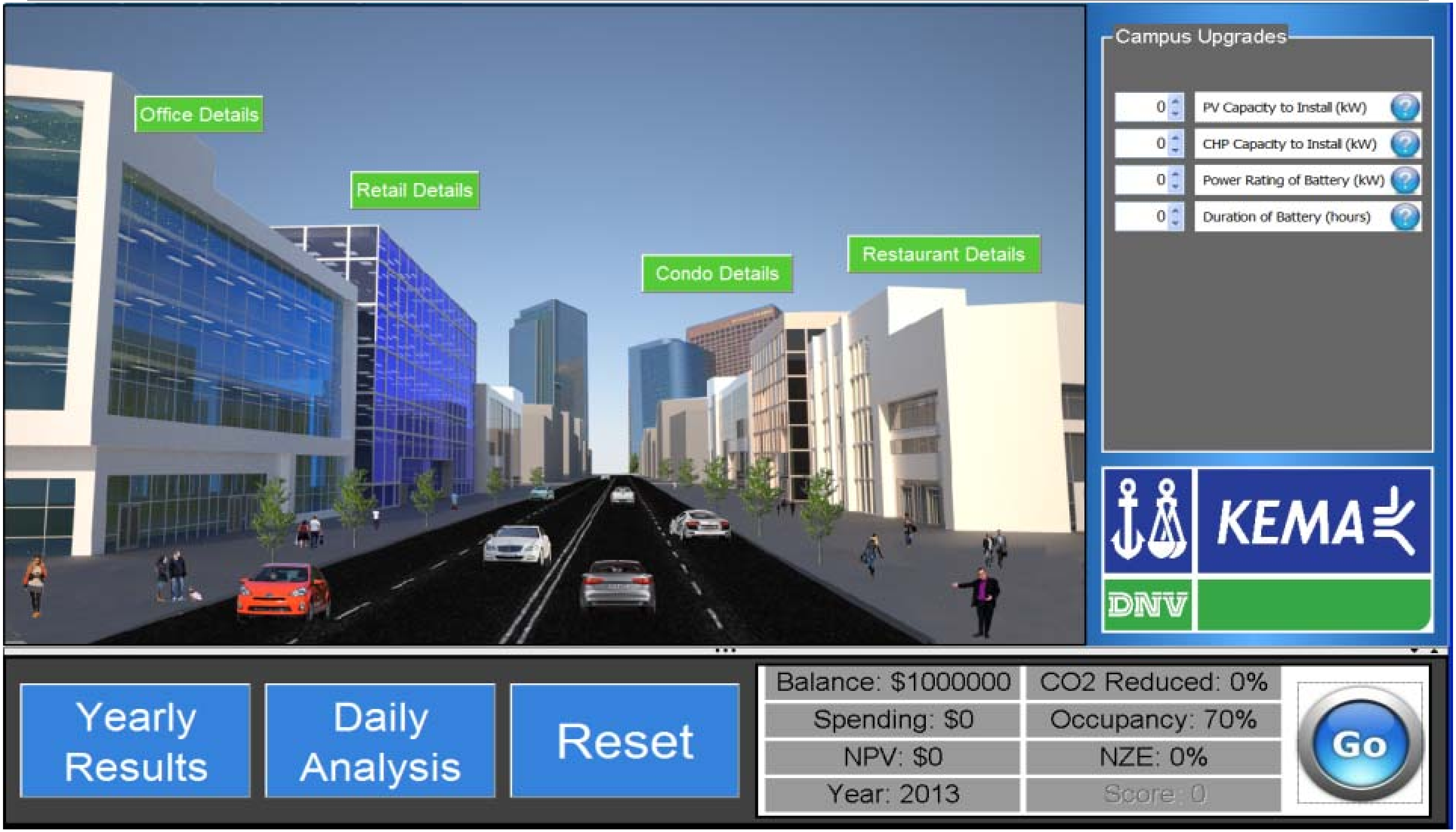
	Problem	Results
CEC	Storage for Wind/Solar Integration	Identification of Ramping issues Est. of Ramp/Storage needs & Benefits
CA ISO	Design of Advanced AGC Integration of CST with Storage	CST Dynamics Advanced AGC Design Fast Ramping Simulations
CEC	CST Technologies	Detailed modeling / valuation of thermal storage
PJM	Pay for Performance & FERC Filing for 755 Tariff	Quantification of Fast Regulation Resources Benefits & Tariff Justification
ERCOT	Integration of Wind	In progress
TenneT (NL)	Wind integration	15 minute scheduling protocol
Hawaiian Electric Co	Wind / solar integration	Design of special AGC controls
ISO NE	New effort	Renewables integration, AGC design
Sandia	Fast Resource Valuation	Emissions performance of Fast Resources for Regulation

Graphical User Interface

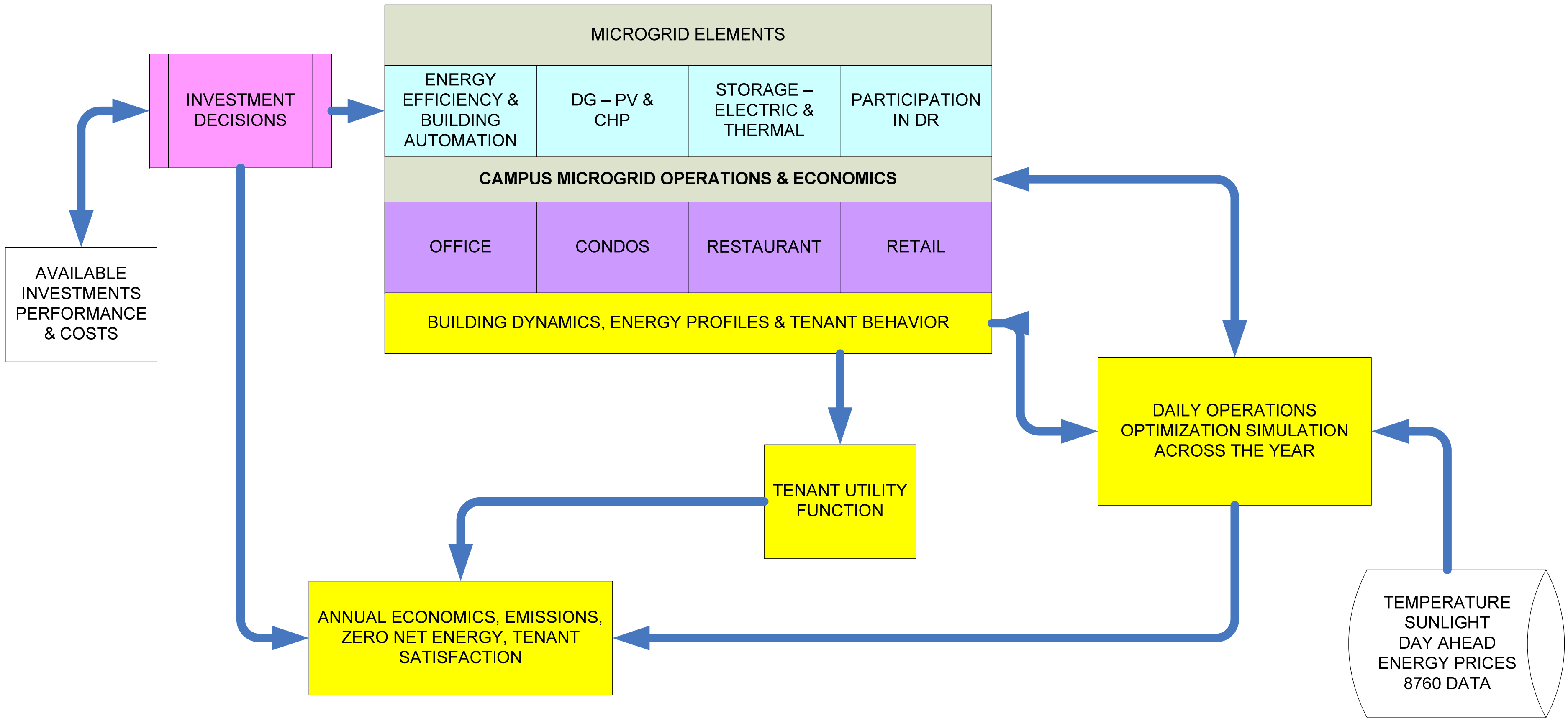


- Conventional Generation
- Renewables
- Load and interchange
- Day-ahead schedules
- AGC and frequency
- Markets and RTD
- Storage
- 24h simulation with second-minute data

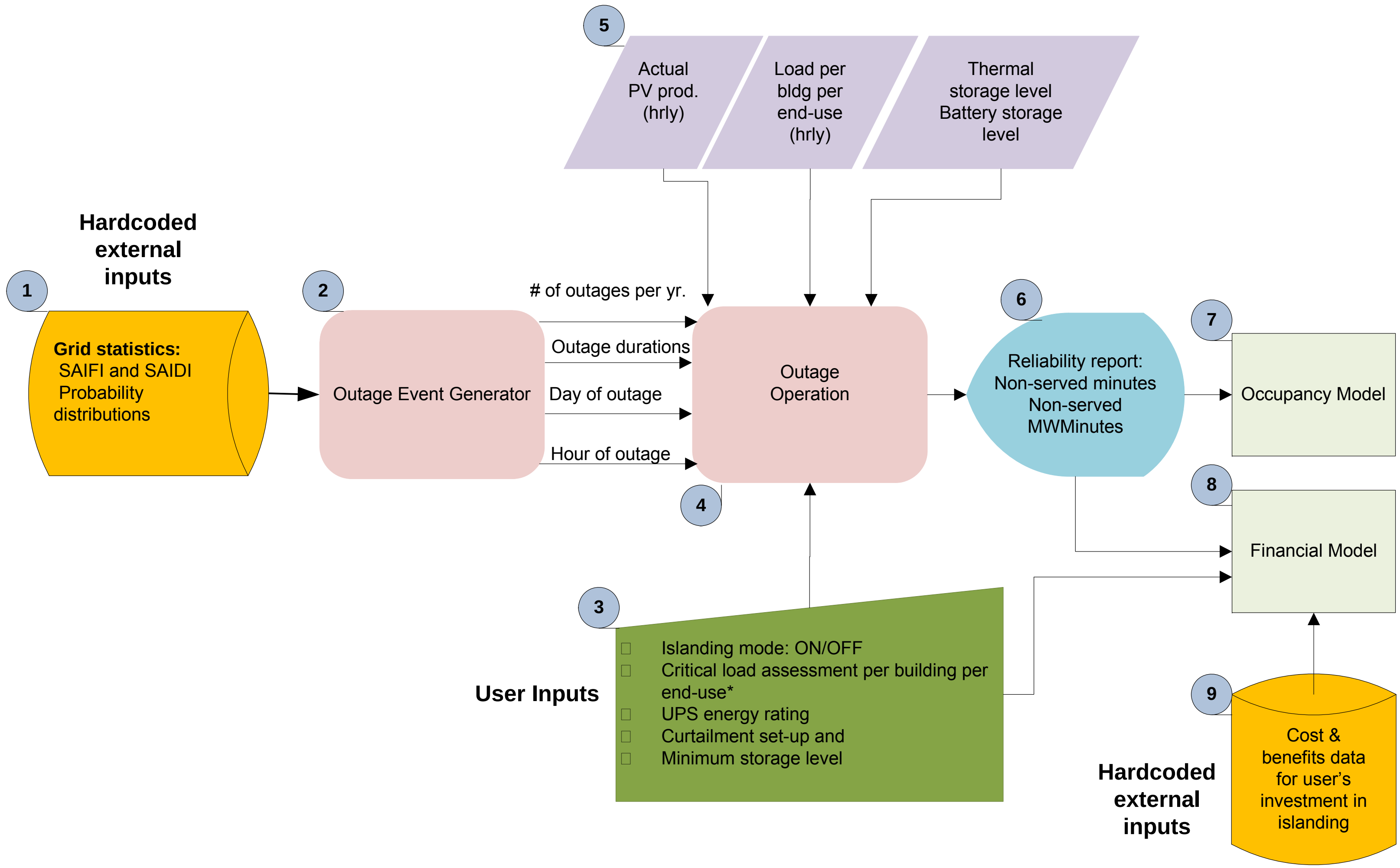
Summary MicroGrid Optimizer
Based on Interactive Technical and Commercial models



MGO Captures all Microgrid Economics



MGO Assesses Islanding and Reliability Performance



DNV KEMA MGO is Latest Development

- Detailed Sophisticated Modeling and Analytics
  - Includes Building Models and Building Automation
    - Data bases of Buildings and ASHRAE models
  - Detailed Energy market information (CA ISO LMPs) (forward gas curves)
  - Local Weather – temperature and insolation
  - Data bases of DG performance and economics
  - Data bases of Thermal and Electrical storage assets
  - Values different assets (incl storage) in context of overall “behind the meter” assets and operations
- Has been used to screen state and city facilities
- Includes benefits of
  - Time arbitrage
  - Local reliability
  - Demand response
  - Provision of ancillaries (reserve, regulation)
  - Reduced demand charges

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Use Case 1: Distributed Storage

Application (use case)	Description/ Problem Solving	Potential Compensation or Ownership	Likely Siting & Scale (C x hr)	Storage Solution	Conventional Solutions or Alternatives	Energy Storage Case Study Example
Distribution Storage	Defers distribution upgrades (✓) (For Example: overloaded wire, transformers, capacitor–not a load modifier!) Use energy storage in lieu of sub transmission capacity (for 1-4 years) (✓)	• Utility Rate-based • Third party • End User	• At or down-stream from overloaded equipment • Substation • Circuit ➢ **1MWx 4 hrs**	• Upgrade Deferral* • Replacement Deferral* • Equipment life extension • Service reliability • T&D congestion • Transportability	• Upgrade wires or transformers • ***Or Add a transformer***	• SDG&E primary distribution storage (batteries)

(✓) Designates Problems Covered by DNV KEMA Tool → **Storage Distribution Valuation Tool**

Note 1: Simulation tools allows for the ability to “add a transformer” to the solution

Use Case 2: Community Energy Storage

Application (use case)	Description/ Problem Solving	Potential Compensation or Ownership	Likely Siting	Primary End Uses	*Conventional Solutions or Alternatives*	Energy Storage Case Study Example
Community Energy Storage@	Improve local service reliability. (✓) Integration of distributed VREs (✓) Voltage control (✓)	• Utility Rate-based • Third Party under contract	• Adjacent to loads, on utility 'easement' >25 kW x 2 hr	• Service Reliability* • D Deferral* • T Congestion* • Electric Supply* • Ancillary Services* • Transportability	• Capacitor • Transformer • **Controls**	• AEP CES • Detroit Edison CES • SMUD Solar Smart RES/CES Project • SDG&E secondary storage projects

(✓) Designates Problems Covered by DNV KEMA Tool → **Storage Distribution Valuation Tool**

Note 1: SDVT adds "controls" capabilities to analysis
Note 2: T. Congestion is really a price arbitrage case (location price signal)

Credential: Currently being utilized to evaluate Detroit Edison ARRA CES Project

Use Case 3: Distributed Peaker Model

Application (use case)	Description/ Problem Solving	Likely Compensation or Ownership	Likely Siting	Primary End Uses	Conventional Solutions or Alternatives	Energy Storage Case Study Example
Distributed Peaker@ (Load Modifier -- primarily in lieu of added electric supply capacity)	Energy cycling to address peaking needs (✓) (part year operated by utility, part year operated by CAISO)	• Utility Ratebased • Third Party ownership, PPA	• Sub-transmission • Substation **>25 MW x 4 hr**	• Electric Supply* • Ancillary Services* • T Congestion* • Service Reliability* • D Deferral* • Transportability	• Conventional Generation (CT, CC) • PPA • DR • Critical Peak Pricing (CPP) • EE TES	• Modesto Irrigation District • Raleigh, NC (TAS Energy)

(✓) Designates Problems Covered by DNV KEMA Tool → **Storage Peaker Model**

Use Case 4 – VER-sited renewables

Application (use case)	Description/ Problem Solving	Potential Compensation or Ownership	Likely Siting	Primary End Uses	Conventional Solutions or Alternatives	Energy Storage Case Study Example
VER-sited (renewables)	On-site firming or shaping of intermittent generation (✓)	• Expended by LSE (if third party owns and sells higher value power to LSE) • Ratebased (If IOU owns and pairs with generation)	• At or near RE Generation • Sub-transmission • Substation • Distribution **35 MW – 250 MW**	• Variable RE Generation Integration • Energy time-shift • Capacity-firming • Ramping • Volt/VAR Support	• *Additional Sub-T or D Infrastructure* • *Static VAR Compensator* • *Switched Capacitor Banks* • Generation storage technologies	• Xtreme Power - various • Solar Thermal with molten salt or other • TAS Generation Storage™ • Laurel Mtn AES

(✓) Designates Problems Covered by DNV KEMA Tool → **KERMIT / PLexos Tools**

Note 1: Using Plexos for scheduled – day ahead, hourly (> 5 minute time frame)
Note 2: Using KERMIT for real time dispatching, regulation (< 5 minute time frame)

Credential: Currently utilizing Plexos on CEC Concentrating Solar Thermal Study
Credential: Utilized KERMIT for studies with CAISO, CEC

Use Case 5: Bulk Generation Storage

Application (use case)	Description/ Problem Solving	Potential Compensation or Ownership	Likely Siting	Primary End Uses	Conventional Solutions	Energy Storage Case Study Example
Bulk Generation/ Storage	Electric Supply Capacity/ provides resource adequacy, ancillary services, and energy (✓)	• Market • Utility Ratebasing • Third Party	• Transmission • Generator co-located **>100 MW x 6 hr**	• Resource adequacy • Ancillary services • Energy	• Conventional Generation (CT, CC) • PPA • DR	• Utility-owned Pumped Hydro-electric • Alabama CAES • TAS Energy Generation Storage™ Case Study

(✓) Designates Problems Covered by DNV KEMA Tool → **KERMIT / PLexos Tools**

Credential: Utilized tools for Bulk storage studies with CEC, California CST Project, and European 2050 Electric & Gas Energy Plan

Credential: Utilized KERMIT for PJM FERC Filing for Fast Response Storage

Use Case 6: Demand Side Management

Application (use case)	Description/ Problem Solving	Likely Compensation or Ownership	Likely Siting	Primary End Uses	Conventional Solutions or Alternatives	Energy Storage Case Study Example
Demand Side Management	End-use Customer Bill Management (✓) System load modification (✓) Service Reliability/ Quality (✓)	• Customer • Market (for ancillary services) • End-user • Third-party • *Utility Ownership?*	• Customer-side of Meter	• TOU Energy Cost Management • Demand Charge Management • Reliability (back-up power) • Power Quality • Ancillary Services *	• Energy Efficiency • Combined Heat and Power (CHP) • Combined Cooling Heat and Power (CCHP)	• Alameda County Santa Rita Jail • Various SGIP funded projects • TES • Tesla/Solar City?

(✓) Designates Problems Covered by DNV KEMA Tool → **Microgrid assessment tool**

Note 1: Can conduct a demonstration for the microgrid model per request
Note 2: Classic DR, Back-up, Regulation for an End-User → Replacement for current traditional UPS

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  - Distribution Valuation Tool

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